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Definition of Fuel Ignition Delay Based on Running Process Diesel Engine Mathematics Modeling Method

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Abstract

A mathematical modeling technique applied to the processes, occurring in internal combustion engines, is a powerful instrument that allows discovering the laws inherent in the processes. Fuel injecting process, mixture formation process and following combustion process are the most complex concealed processes, however the investigation of those is possible and brings some good results when the math instrument mentioned above is used. The significant parameter infused on engine behavior is so-called fuel ignition delay. The article presents the analysis of existing empiric-analytical dependences for the definition of fuel ignition delay in diesel engines. It is shown, that in order to estimate fuel ignition delay researchers widely use the formula offered by prof. A.I. Tolstov, which gives overstated estimation of this parameter with regards to diesel engine without supercharging. For the purpose of mathematical modeling of the process in a diesel engine without supercharging it is suggested to correct the formula A.I. Tolstov by adjusting the empiric coefficient included in the formula.

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Keywords: diesel engine processes; fuel ignition delay; fuel injection; mathematical modeling

1. Introduction

Mathematical modeling is the power instrument applied for investigation the processes of various complex technical systems. Particularly, the math modeling started developing in the middle of last century and at preset is widely used for processes investigation of internal combustion engine systems [1, 2].

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Application of math modeling method is especially effective for investigating within the cylinder processes (processes of fuel injecting, mixture formation, fuel burning, heat exchanging), and the processes within fuel supply equipment [3-5].

It should be emphasized that detailed knowledge the processes features, processes interconnections is especially actual at present, when the electronic microprocessor control systems are developing [6]. Such a type control systems ensures significant improvement technical, economic and ecological characteristics of engines.

While developing the mathematical model of diesel engine running process, which should adequate describes processes, it is necessary to have an information about function dependences fuel ignition delay (IgnD) from current parameters inside the cylinder at the moment of fuel injection1. Fuel ignition delay period is an important parameter, influencing on character process inside the cylinders of diesel engines, as well on engines economy and on ecological characteristics.

2. Investigations of IgnD

For the first time analysis of the factors, that have an influence on *IgnD* and formulas for definition that parameter in Russia were offered in the middle the last century by researchers N.N. Semenov, A.S. Sokolik, A.I. Tolstov [7-9]. The recent publications, which analyse the formulas for *IgnD* are [10, 11]. The most complete analyse of formulas for *IgnD* definition high-speed diesels is included in scientific work R.Z. Kavtaradze (MSTU named. N.A.Bauman) [12]. With regard to slow speed diesel the analysis formulas for *IgnD* definition based on the theory of similarity can be found at [13].

It should be emphasized, that up to the present there is no absolutely reliable mathematical description of the dependences fuel ignition delay from influenced factors. Proposed by various authors formulas for *IgnD* definition give essential distinctions in results, that explained to complexity of *IgnD* forming mechanism (depend on fuel properties, charge parameters into the cylinder at the moment when fuel is start injected, temperature of the combustion chamber walls, dispersion degree of fuel and so on). In scientific work [14] prof. N.F. Razleytsev propose to apply for *IgnD* (τ_i) definition formula prof. A. I. Tolstov

$$\tau_i = 10^{-2} B \left(\frac{T_{\text{start inj}}}{p_{\text{start inj}}} \right)^{0,5} e^{\frac{E_i}{RT_{\text{start inj}}}} , \qquad (1)$$

where $B = B_0 \left(1 - kn\right)$; $B_0 = 3,8 \cdot 10^{-4}$; $k = 1,6 \cdot 10^{-4}$; $p_{\text{start inj}}$, $T_{\text{start inj}}$– pressure (MPa) and temperature (K) of cylinder charge at the moment of start fuel injecting; E_i – relative activation energy of pre-ignition reactions, E_i=(21…25)·10^3 kJ/kilomole ; R – universal gas constant, R=8,312 kJ/(kilomole·K).

Given formula is the most popular among researchers; however analysis with regard to diesels without supercharging shows up necessity amendment of empirical coefficients.

Let ought to pay attention to components (multipliers), included to formula (1):

$B_0 = 3,8 \cdot 10^{-4}$ - empirical coefficient, matched to experimental results, obtained during tests of locomotive diesels;

$\left(1 - kn\right)$ - multiplier, included empirical coefficient *k*, that evaluates influence engine speed (evaluates influence turbulence of charge in the engine cylinder);

$\left(\frac{T_{\text{start inj}}}{p_{\text{start inj}}} \right)^{0,5}$ - multiplier, evaluates influence charge density (oxygen) in volume unity of combustion chamber (at the moment fuel injection);

[1] fuel ignition delay – time period between beginning fuel injection into the engine cylinder and beginning of fuel ignition (beginning «visible» combustion).

$e^{\frac{E_i}{RT_H}}$ - multiplier (exponential function), that evaluates rate pre-ignition reactions based on chemical kinetics postulates.

Fig.1 shows pressure curve $p_{cyl}(\varphi)$ and temperature curve $T_{cyl}(\varphi)$ of compression stroke for diesel without supercharging (diesel Д-243E, cylinder diameter D=110mm, piston stroke S=125mm, compression ratio ε=16). The curves obtained with mathematic modeling method. As we can see within observed angle range of crank position (CPAngle) φ= -30 … 0 degree, cylinder pressure changes in the range p_{cyl}=1,44…4,25 MPa, temperature changes in the range T_{cyl}=670…872 K. That is to say, for considered diesel engine the sufficient temperate levels of parameters $p_{start\ inj}$ and $T_{start\ inj}$ can be seen. All that could lead to delaying of the process fuel ignition.

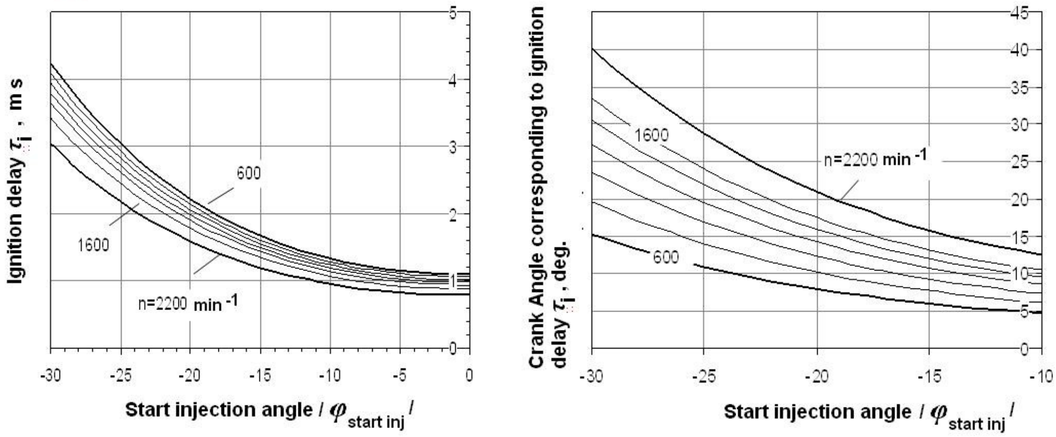

Fig.1. Pressure and temperature variations inside the cylinder of d.e. Д-243E while beginning of fuel injection (compression stroke, φ= -30…0 deg.)

3. Analysis of IgnD variation

Fig.2 shows variation of the parameters *IgnD* (τ_i) and *IgnD* (φ_i) as function of start injection angle $\varphi_{start\ inj}$, obtained with formula (1).

As can be seen, within viewed range parameter $\varphi_{start\ inj}$ and engine speed n the ignition time delay changes in range τ_i =0,8…4 ms and the angle delay changes in range φ_i = 5…40 deg. of CPAngle. Of course, engine speed increasing, as well as increasing of the angle injection advance result in increase values of parameter φ_i (up to $\varphi_i \approx$ 30 … 40 deg. of CPAngle).

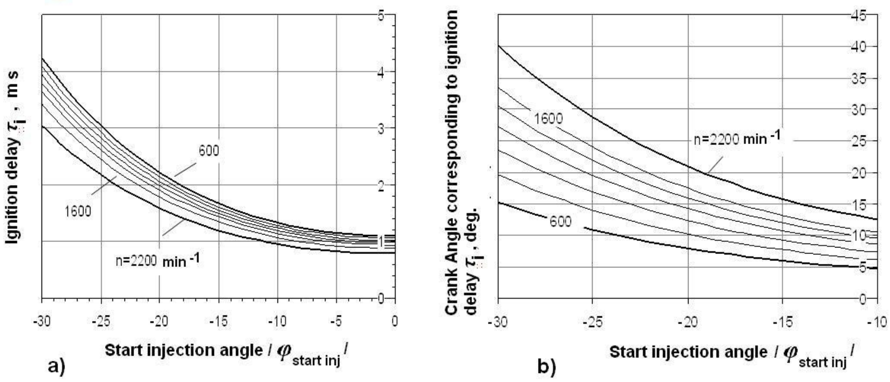

Fig.2. Variations of ignition delay parameters τi (a) and φi (b) depending on fuel start injection φstart inj (determined with formula (1)) (d.e. Д-243E)

At fig.3 based on calculated results function(s) φstart ign = f(φstart inj) are presented (for different engine speed n).

Let us analyze obtained functional relation for engine speed n=2200 min-1. Fig.3 shows, that if fuel is injected (start is injected) closely to top dead center (TDC) fuel start burning approximately at +10 deg. of CPAngle (in other words after TDC). If fuel is injected at CPAngle = -15…-20 deg. fuel start burning approximately at TDC (φstart ign ≈ 0 deg. of CPAngle). However, if fuel is injected at CPAngle = -30 deg., as we can see at fig.3, fuel in spite of such «early» injection starts burning at CPAngle = +10 град. (that is to say, again far after TDC). All mentioned contradict physics of occurring processes. In investigated variation range φstart inj function dependence φstart ign=f(φstart inj) is not monotonous increasing one. This fact indicates the function incorrectness for area, where advance of fuel injection is considerable (for φstart inj <-15 deg. of CPAngle). Incorrect description area given formula (1) identified at fig.3 with circle and dotted line.

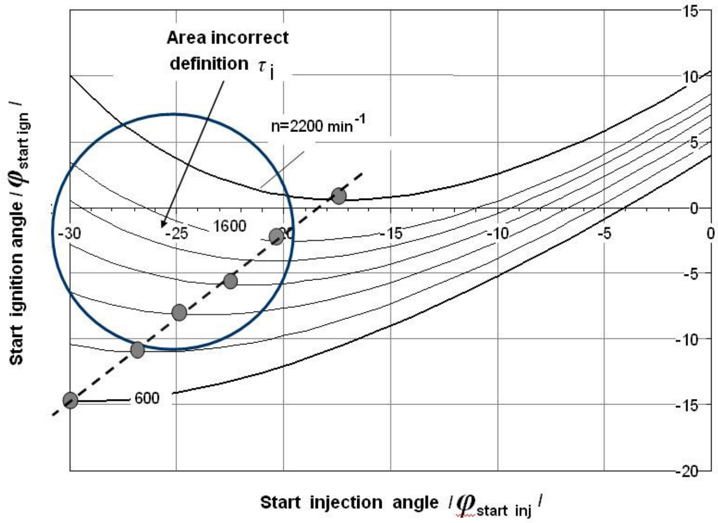

Fig.3. Variation of start ignition angle φstart ign depended on start injection angle φstart inj (for different engine speed within range n=600…2200 min-1)

Correction the formula (1) for improving description the parameter τi in area, applicable «early» injection might be perform by means of changing the coefficient B0 (look at formula (1)). At fig.4 functions τi=f(φstart inj) (a) and φstart ign=f(φstart inj.) (b), obtained with corrected value B0=2,5 are presented.

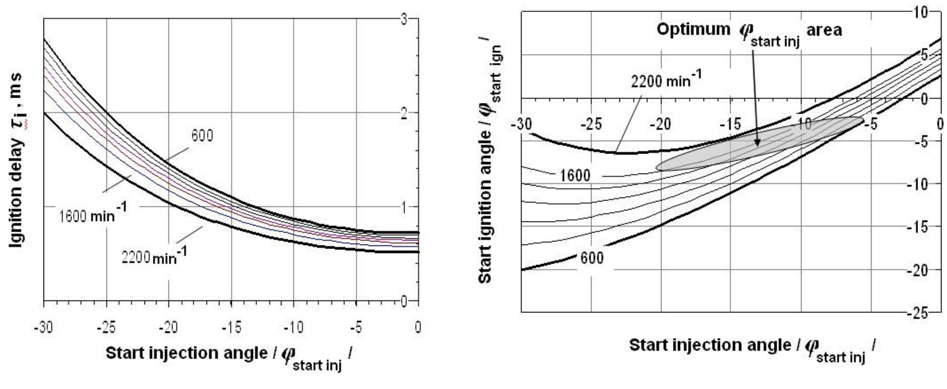

Fig.4. Functions τi=f(φstart inj) (a) and φstart ign=f(φstart inj.) (b), obtained with corrected value B0=2,5

Thus as a result of correction B_0 the more flat function curves $\tau_i = f(\varphi_{start\ inj})$ for different engine speed were obtained. Maximum value *IgnD* at n=600 min^{-1} equals approximately 3 ms (at $\varphi_{start\ inj}$ = -30 deg. of CPAngle), at n=2200 min^{-1} - 2 ms. Respectively curve forms $\varphi_{start\ ign} = f(\varphi_{start\ inj})$ have changed.

As we can see at fig.4,b at n=2200 min^{-1} for «early» injections significant bending up for all curves are not observed, although it should be noted that in range $\varphi_{start\ inj}$ = -15…-30 deg. of CPAngle variation of this parameter will not cause significant variation parameter $\varphi_{start\ ign}$. (increase of advance for fuel injection angle will be compensated with increase of the angle that will correspond ignition delay).

It is known from literary sources, that in operating regimes of diesels (which are close to nominal regime) angles $\varphi_{start\ ign} \approx$ -5 deg. of CPAngle are the optimum ones. In regimes of partial power and regimes of no-load conditions the angle of start ignition (respectively, the angle of start injection) could be shifted close to TDC or even fixed at some degree after TDC ($\varphi_{start\ ign} \approx$ 0…+5 deg. of CPAngle). Proceeding from above mentioned at Fig.4, b the area of optimum start injection angles $\varphi_{start\ inj}$, is indicated. Those angles ensure optimum timing for fuel ignition in engine cylinder (depending on regime speed).

4. Conclusion

The structural and quantitative analysis of formula A.I.Tolstov for estimation fuel ignition delay (*IgnD)* in non-supercharged diesel engine was carried out. It is shown, that fuel *IgnD* value given with the formula for non-supercharged diesel and for «early» injections is not correct. At present the experimental research regarding fuel *IgnD* verification is going on.

References

[1] D.N. Virubov, N.A. Ivaschenko, Internal combustion engines, Theory of piston and combined engines, Mashinostroenie, Moscow, 1983.
[2] N.H. Diachenko, A.K. Kostin, Theory of internal combustion engines, Mashinostroenie, Leningrad, 1974.
[3] I.V. Astakhov, V.I. Trusov, A.S. Hachiyan, Fuel supply and atomization in diesels, Mashinoctroenie, Moscow, 1972.
[4] J.J. Broeze, Combustion in Piston Engines, Spark-Ignition and Compression-Ignition, Mashinostroenie, Moscow, 1989.
[5] U.B. Sviridov, L.V. Maliavinskiy, M.M. Vikhert, Fuel and fuel supply in automobile and tractor diesels, Mashinostroenie, Leningrad, 1979.
[6] F.I. Pinskiy, R.I. Davtian, B.J. Cherniak, Microprocessor control system for automobile internal combustion engines, Legion-Autodata, Moscow, 2002.
[7] N.N. Semenov, A chain reactions, ONTI, Leningrad, 1934.
[8] A.S. Sokolik, About physicochemical nature spontaneous ignition and combustion in engine with ignition resulted in compression, CNIDI-VNITOA. 18 (1951).
[9] A.I. Tolstov, Indicated ignition delay period and cycle dynamics of high-speed engine with ignition resulted in compression, in: Proceeding of collected papers Research process of highspeed engines, Transaction of research laboratory engine. 1 (1955) 5–55.
[10] A.A. Gavrilov, A.N. Gots, Duration of ignition delay for fuel-air mixture in piston engines, Fundamental research. 6 (2014) 703–708.
[11] V.M. Slavuskiy, E.A. Salikin, V.V. Slavutskiy, A analysis of factors, that determine delay of fuel ignition in diesels, Series Processes of energy transformation and energy plants, Izvestia VGTU. 99 (2012) 51–54.
[12] R.Z. Kavtaradze, Theory of piston engines, Special chapters, Publisher MGTU of N.A. Baumana, Moscow, 2008.
[13] V.V. Lakhanin, O.N. Lebelev, V.S. Semenov, K.E. Chueshko, Modeling the processes in marine piston engines and machinery, Publisher Sudoctroenie, Leningrad, 1967.
[14] N.F. Razleytsev, Modeling and optimization the combustion process in diesels, Visha shkola, Publisher of Kharkov universitet, Kharkov, 1080.